Transformer Design Considerations
Component Selection

Core
Bobbin
Wire
Tape
Clip
Adhesive
Varnish
Core Selection

- **Power vs Switching Frequency**

**Low Power**
EP7: For a DC-DC flyback operating at 100kHz, this core can supply up to 3W

**High Power**
ETD39: For a DC-DC flyback operating at 100kHz, this core can supply up to 400W
Core Selection

- Operating frequency guides us to the right core material and core losses

TP4 (TDG 2018: 20)
~1060 Pcv(KW/m3) loss @ 100mT, 500kHz

TP5 (TDG 2018: 36)
~700 Pcv(KW/m3) loss @ 100mT, 500kHz
Bobbin Selection – Material

- **Thermoplastic (PBT, PET, LCP)**
  - ▲ Easy to mold
  - ▲ Flexible
  - ▼ Low melt point
  - ▼ Easily deformed

- **Thermoset (PM9820, AM-113, WH9100)**
  - ▲ High Temperature (soldering)
  - ▲ Robust
  - ▼ Less flexible
  - ▼ Difficult to mold
Wire Selection

- Chosen wire depends on safety grade and dielectric requirements
  - Single insulation magnet wire
  - Heavy insulation magnet wire
  - Basic / Supplementary insulation
  - Triple Insulated Wire (TCA3 or TEX-E)
  - Fully Insulated Wire
  - Litz wire
Transformer’s Parasitics

- DC Resistance, Leakage Inductance and Inter/Intrawinding Capacitance
DC Resistance and Capacitance

- **DC Resistance** is a direct function of wire thickness. The resistance can be reduced by using thicker wire or multiple strands in parallel.

- **Intrawinding Capacitance** on the Primary side can increase switching losses. This can be reduced by using thicker insulated wire to increase the distance between turns.

- Split primary windings can result in unbalanced **interwinding capacitance** potentially leading to EMI issues but it is a prefer method to reduce leakage inductance. This can be reduced by separating the primary and secondary windings as much as possible, e.g. tape, shield or auxiliary wind between PRI and SEC.
Leakage Inductance

Leakage inductance is a measure of how much magnetic flux couples from the primary into the secondary. The greater the distance between the primary and the secondary, the fewer flux lines there will be to couple the two windings together. Fewer flux lines coupling the windings means larger values of leakage inductance.

Line of magnetic flux that doesn’t link the primary to the secondary.
Leakage Inductance

- Common causes of leakage inductance

- Centre-flange
- Sloping coils

- Sloping coils
- Uneven tape

- Too many tape layers
- Tape too thick
Leakage Inductance

- Maximizing coupling between PRI and SEC

\[ L = 3.194 \times \text{MLT} \times N \times (h + b/3) \times 10^5 \times w^4 s^2 \]

To improve the coupling between the windings we can sandwich the first winding around the second. This reduces the average distance between the windings and results in \(1/4\)th the original value of leakage inductance – at the expense of more winding labor.
Common Safety Standards

- IEC60950-1 Safety of information Technology Equipment
- IEC60601-1 Safety of Medical Electrical Equipment
- IEC61010-1 Safety of Measurement Control and Laboratory Equipment
- IEC61558-1 Safety of Power transformers and Power Supplies.
- The New safety standard IEC62368-1 -> Audio Video and information technology equipment

- UL1446 Electrical Insulation Systems (Temperature class only)
Common Inputs Required

- Material Group according to Comparative Tracking Index (CTI)
- Insulation Grade
- Pollution Degree
- Overvoltage Category
- RMS Working Voltage
- Peak Working Voltage
- RMS Mains Voltage
Material Group – Tracking Index

- The voltage which causes tracking after 50 drops of 0.1% ammonium chloride solution have fallen on the material. The results of testing at 3 mm thickness are considered representative of the material's performance in any thickness.

- Tracking is an electrical breakdown on the surface of an insulating material. A large voltage difference gradually creates a conductive leakage path across the surface of the material by forming a carbonized track.

<table>
<thead>
<tr>
<th>IEC rating(Material Group)</th>
<th>UL rating (PLC)</th>
<th>Comparative Tracking Index (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0</td>
<td>≥ 600V</td>
</tr>
<tr>
<td>II</td>
<td>1</td>
<td>400V ≤ CTI &lt; 600V</td>
</tr>
<tr>
<td>IIIa</td>
<td>2</td>
<td>250V ≤ CTI &lt; 400V</td>
</tr>
<tr>
<td>IIIb</td>
<td>3</td>
<td>175V ≤ CTI &lt; 250V</td>
</tr>
<tr>
<td>None</td>
<td>5</td>
<td>100V ≤ CTI &lt; 175V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0V ≤ CTI &lt; 100V</td>
</tr>
</tbody>
</table>

Best material
Insulation Grades

Several grades of insulation are defined for each standard

- **Functional Insulation** - Is only necessary for the correct functioning of equipment and does not provide any protection against electric shock.

- **Basic Insulation** - Insulation applied to live parts to provide basic protection against electric shock.

- **Supplementary Insulation** - Independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the even of a failure of basic insulation.

- **Double Insulation** - Comprising both basic insulation and supplementary insulation.

- **Reinforced Insulation** - Single insulation system applied to live parts which provides a degree of protection against electric shock equivalent to double insulation.
Pollution Degree

IEC 60950-1 defines pollution degree as below:

- **Pollution Degree 1** applies where there is no pollution or only dry, non-conductive pollution. The pollution has no influence. Normally, this is achieved by having components and subassemblies adequately enclosed by enveloping or hermetic sealing so as to exclude dust and moisture (see 2.10.12).

- **Pollution Degree 2** applies where there is only non-conductive pollution that might temporarily become conductive due to occasional condensation. It is generally appropriate for equipment covered by the scope of this standard.

- **Pollution Degree 3** applies where a local environment within the equipment is subject to conductive pollution, or to dry non-conductive pollution that could become conductive due to expected condensation.
# Overvoltage Category

- **Overvoltage categories by IEC 60950-1**

<table>
<thead>
<tr>
<th>Overvoltage category</th>
<th>Equipment and its point of connection to the AC MAINS SUPPLY</th>
<th>Examples of equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>Equipment that will be connected to the point where the AC MAINS SUPPLY enters the building</td>
<td>Electricity meters, Communications information technology equipment for remote electricity metering</td>
</tr>
<tr>
<td>III</td>
<td>Equipment that will be an integral part of the building wiring</td>
<td>Socket-outlets, fuse panels and switch panels, Power monitoring equipment</td>
</tr>
<tr>
<td>II</td>
<td>PLUGGABLE or PERMANENTLY CONNECTED EQUIPMENT that will be supplied from the building wiring</td>
<td>Household appliances, portable tools, home electronics, Most information technology equipment used in the building</td>
</tr>
<tr>
<td>I</td>
<td>Equipment that will be connected to a special AC MAINS SUPPLY in which measures have been taken to reduce transients</td>
<td>Information technology equipment supplied via an external filter or a motor driven generator</td>
</tr>
</tbody>
</table>
Working Voltage

- The highest voltage that the insulation under consideration is or can be subjected to under normal operating conditions.

VDE: Instruction – Operating voltage (2010:1)
Creepage and Clearance

- Creepage and Clearances distances (safety distances) determined by:
  - Working voltage (maximum system voltage between PRI & SEC)
  - Bobbin Material Group (Comparative Tracking Index “CTI”)
  - Insulation grade (Basic, Supplementary, Reinforced)

- Example for safety standard IEC60950-1:
  Working Voltage = 320 Vrms
  Working voltage peak = 400 Vpeak
  Main supply voltage = 240Vrms
  Material Group = 3
  Overvoltage CAT = II
  Insulation Grade = Basic Insulation

  From safety standard tables:
  Dielectric Voltage = 1500VAC, Creepage = 3.2mm, Clearance = 2mm
## Creepage and Clearance

- **Minimum creepage distances for Basic insulation:**

  | RMS Working Voltage (V) | Material Group | Pollution Degree 1<sup>a</sup> | Pollution Degree 2 | Pollution Degree 3
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Printed boards</td>
<td></td>
<td></td>
<td>Other materials</td>
</tr>
<tr>
<td></td>
<td>I, II, IIIa, IIIb</td>
<td>I, II, IIIa, IIIb</td>
<td>I, II, IIIa, IIIb</td>
<td>I, II, IIIa, IIIb</td>
</tr>
<tr>
<td>10</td>
<td>0.025, 0.04</td>
<td>0.06, 0.4</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>12.5</td>
<td>0.025, 0.04</td>
<td>0.09, 0.42</td>
<td>0.42</td>
<td>1.05</td>
</tr>
<tr>
<td>16</td>
<td>0.025, 0.04</td>
<td>0.11, 0.45</td>
<td>0.45</td>
<td>1.1</td>
</tr>
<tr>
<td>20</td>
<td>0.025, 0.04</td>
<td>0.11, 0.48</td>
<td>0.48</td>
<td>1.2</td>
</tr>
<tr>
<td>25</td>
<td>0.025, 0.04</td>
<td>0.125, 0.5</td>
<td>0.5</td>
<td>1.2</td>
</tr>
<tr>
<td>32</td>
<td>0.025, 0.04</td>
<td>0.14, 0.53</td>
<td>0.53</td>
<td>1.3</td>
</tr>
<tr>
<td>40</td>
<td>0.025, 0.04</td>
<td>0.16, 0.56</td>
<td>0.56</td>
<td>1.4</td>
</tr>
<tr>
<td>50</td>
<td>0.025, 0.04</td>
<td>0.18, 0.6</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>63</td>
<td>0.04, 0.063</td>
<td>0.2, 0.63</td>
<td>0.63</td>
<td>1.5</td>
</tr>
<tr>
<td>80</td>
<td>0.063, 0.10</td>
<td>0.22, 0.67</td>
<td>0.67</td>
<td>1.6</td>
</tr>
<tr>
<td>100</td>
<td>0.1, 0.16</td>
<td>0.25, 0.71</td>
<td>0.71</td>
<td>1.7</td>
</tr>
<tr>
<td>125</td>
<td>0.16, 0.25</td>
<td>0.28, 0.75</td>
<td>0.75</td>
<td>1.9</td>
</tr>
<tr>
<td>160</td>
<td>0.25, 0.40</td>
<td>0.32, 0.8</td>
<td>0.8</td>
<td>2.0</td>
</tr>
<tr>
<td>200</td>
<td>0.4, 0.63</td>
<td>0.42, 1.0</td>
<td>1.0</td>
<td>2.4</td>
</tr>
<tr>
<td>250</td>
<td>0.58, 1.0</td>
<td>0.56, 1.25</td>
<td>1.25</td>
<td>3.2</td>
</tr>
<tr>
<td>320</td>
<td>0.75, 1.6</td>
<td>0.78, 1.6</td>
<td>1.6</td>
<td>3.6</td>
</tr>
<tr>
<td>400</td>
<td>1.0, 2.0</td>
<td>1.0, 2.0</td>
<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td>500</td>
<td>1.3, 2.5</td>
<td>1.3, 2.5</td>
<td>2.5</td>
<td>4.5</td>
</tr>
<tr>
<td>630</td>
<td>1.8, 3.2</td>
<td>1.8, 3.2</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td>800</td>
<td>2.4, 4.0</td>
<td>2.4, 4.0</td>
<td>4.0</td>
<td>6.3</td>
</tr>
<tr>
<td>1000</td>
<td>3.2, 5.0</td>
<td>3.2, 5.0</td>
<td>5.0</td>
<td>6.3</td>
</tr>
</tbody>
</table>

IEC 60950-1 (2005:214)
## Creepage and Clearance

- Minimum clearances for insulation in primary circuits and between primary and secondary circuits

<table>
<thead>
<tr>
<th>PEAK WORKING VOLTAGE * up to and including V</th>
<th>MAINS TRANSIENT VOLTAGE</th>
<th>Pollution degree</th>
<th>1 and 2 b</th>
<th>3</th>
<th>1 and 2 b</th>
<th>3</th>
<th>1, 2 b and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>B/S</td>
<td>R</td>
<td>F</td>
<td>B/S</td>
<td>R</td>
<td>F</td>
<td>B/S</td>
</tr>
<tr>
<td>71</td>
<td>0.4</td>
<td>1.3</td>
<td>0.6</td>
<td>1.0</td>
<td>(1.0)</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>210</td>
<td>0.5</td>
<td>1.0</td>
<td>0.8</td>
<td>1.3</td>
<td>(1.6)</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>420</td>
<td>1.5</td>
<td>2.0</td>
<td>(1.5)</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>840</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>1400</td>
<td>F/B/S</td>
<td>4.2</td>
<td>R</td>
<td>6.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2600</td>
<td>F/B/SR</td>
<td>6.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 000</td>
<td>F/B/SR</td>
<td>17.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 000</td>
<td>F/B/SR</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 000</td>
<td>F/B/SR</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 000</td>
<td>F/B/SR</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42 000</td>
<td>F/B/SR</td>
<td>130</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values in the table are applicable to functional insulation (F). If required by 5.3.4 a) (see 2.10.13), basic insulation (B), supplementary insulation (S) and reinforced insulation (R). The values in parenthesis apply to basic insulation, supplementary insulation and reinforced insulation only if the manufacturer is subjected to a quality control programme that provides at least the same level of assurance as the example given in Clause R.2. Double insulation and reinforced insulation shall be subjected to routine tests for electric strength.

If the peak working voltage exceeds the peak value of the AC mains supply voltage, linear interpolation is permitted between the nearest two points, the calculated minimum clearance being rounded up to the next higher 0.1 mm increment.

* If the peak working voltage exceeds the peak value of the AC mains supply voltage, see 2.10.3.3 b) regarding additional clearances.

b) It is not required to pass the tests of 2.10.10 for pollution degree 1.

The relationship between mains transient voltage and AC mains supply voltage is given in Table 22.
Examples safety calculator

- WE Midcom Safety calculator for calculation of creepage and clearance (example for 60950-1)

  - Material Group: 3
  - Insulation Grade: Reinforced
  - Pollution Degree: 2
  - Overvoltage Category: II
  - RMS Working Voltage: 265Vrms
  - Peak Working Voltage: 400V
  - RMS Mains Voltage: 265Vrms

  Dielectric Voltage Required = 3000VAC
  Creepage Distance Required = 5.3 mm
  Clearance Distance Required = 4 mm

- Material Group: 3
  - Insulation Grade: Basic
  - Pollution Degree: 2
  - Overvoltage Category: II
  - RMS Working Voltage: 265Vrms
  - Peak Working Voltage: 400V
  - RMS Mains Voltage: 265Vrms

  Dielectric Voltage Required = 1500VAC
  Creepage Distance Required = 2.7 mm
  Clearance Distance Required = 2 mm
Insulated Wire

- **Triple Insulated Wire (TCA3 155°C Class)**
  - Internal safety distances are easily met.
  - Full winding width of bobbin available
  - Not Automatable - (x2) Hand strip & terminate operations per wire
  - Material cost higher than magnet wire
  - Priced by length not weight - (2 x TIW = 2 x $$$)

- **Triple Insulated Wire (TEX-E 130°C UL Class)**
  - Reduced diameter compared to TCA3 – more turns less cost
  - Approved by UL and VDE (extra tests may be required)
  - Not automatable

- **Fully Insulated Wire (FIW 180°C Class)**
  - Lower cost (priced by weight)
  - Automatable (for < AWG30)
  - Only able to be used for 61558-2-16 designs with only VDE approval (not recognized by UL)

- **PFA Reinforced Insulation (180°C Class)**
  - Higher temp rating – prefered for SMD package

<table>
<thead>
<tr>
<th>Wire Type Comparison with Equivalent Copper Cross Sectional Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>9208-0025                                               Scaled to 20x</td>
</tr>
<tr>
<td>9209-0025                                               Scaled to 20x</td>
</tr>
<tr>
<td>9263-0025                                               Scaled to 20x</td>
</tr>
<tr>
<td>9262-0025                                               Scaled to 20x</td>
</tr>
<tr>
<td>9239-0825                                               Scaled to 20x</td>
</tr>
<tr>
<td>9220-0142                                               Scaled to 20x</td>
</tr>
</tbody>
</table>
How to Achieve Creepage Distances

- Use extended rail bobbin and / or margin tape to increase distance from SEC pins to PRI winding

Triple Insulated Wire on SEC to insulate windings

Creepage distance
Design For EMC
Internal Copper foil shielding

- Copper foil is "cuffed" with tape and connected to system ground
  ▲ Shields both conducted and radiated noise
  ▼ Shield must be prepared - labour intensive
  ▼ No auto winding possible
Internal wire wound shielding

- Compact single layer, one end connected to pin and the other buried
  - Shields both conducted and radiated noise
  - Burying lead is manual process

- For automation (and therefore lower cost) both ends of wire shield should be terminated to a pin, can either be with dragback or on other bobbin rail if safety distance allows for this
  - Shields both conducted and radiated noise
  - Fully automatable
External Shielding - Flux Band

- Copper foil is wrapped around coil and core and left floating

▲ Can be added after system level EMC test
▼ Shields radiated noise only
▼ Usually more expensive than internal wire wound shield
External Shielding – core Grounding

- Flying lead (19) connected to copper foil (20) and connected to core using conductive adhesive. Can then be connected to system ground

▲ Can be added to existing transformer if required after EMC test
▲ Good results seen compared to flux band solution
▼ Expensive compared to internal wire wound shield
External Shielding – closed core

- EP7 enclosed core provides shielding properties due to closed core

▲ Little to no cost adder
▲ Build in solution
External Shielding – cap

- EFD 20 with external shield

▲ Easy to assemble
▲ Can be added after design

▼ Shielding function only secondary (primary purpose pick and place)
Design For Manufacturing
Why do we do DFM?

- **To increase reliability**
  - Adapt the design to use proven and repeatable processes

- **To reduce cost**
  - Use automated processes where possible
  - Reduce scrap

- **To reduce lead time**
  - Higher throughput using standard processes
  - Reduce rework
  - Use standard components
Transformer Manufacturing Processes

- Winding
- Termination
- Soldering
Winding

Considerations:

- Pinout
- Layering
- Dragbacks
Pinout – Wires crossing

Wire crossings can cause both mechanical and dielectric stress

This is the ideal pin assignment
Wire Dragbacks

- Dragbacks can be damaged by winding pressure from subsequent layers
  - Start tape before dragback (higher labour)

- 90° dragbacks increase labor and may need extra tape

- Spiral dragbacks can cause core fit issues
Layering

- Adjust wire diameter and number of strands to fill layers

- Choose pinout that promotes good layering
  - Same rail pinout for even number of layers
  - Cross bobbin pinout for odd number of layers

The coil on the right uses a two-bi winding to achieve the same DC resistance, but better layering.
Termination

- Specify wire and pin combinations that can utilize pull-break termination if possible
  - Pins with sharp edges are more suitable for pull breaking
  - Automated winding requires pull breaking

- For very heavy wire, through hole bobbins may be required

- Avoid heavy wire on surface mount terminals
  - Co-planarity issues
  - Height issues
  - Use parallel winding splits and extra terminals for high current windings
Soldering

- A large single strand is more difficult to solder than multiple lighter strands
  - Large strands: more heat, more time - more insulation damage

- Avoid using heavy or litz windings on same bobbin rail with fine wire windings
  - Ideally windings on same bobbin rail should be within 3 gauges

- Sometimes it makes sense to use heavier wire than necessary for soldering – e.g. matching aux wire size to primary, even if current density doesn’t require it (also reduces BOM)
  - May need two soldering operations if wire mismatch is unavoidable
Solder Terminations

- Large wire terminations on TH parts can cause height issues

Large Wire Wraps – this is where part will actually contact PCB

Bobbin Standoff – this surface should contact PCB
To Summarize....

Design For Manufacturing:

The practice of considering the manufacturing process during the design stage

To increase reliability

To reduce cost and lead time

Involve us as early as possible in design phase!
Thank you!

Please contact:
Stephan Rex – Sales Manager
stephan.rex@we-online.com
Design for DC Magnetic Immunity
Transformer Parameters

- Electrical Specification and Saturation

**ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.C. RESISTANCE</td>
<td>@20°C</td>
<td>0.5170 ohms ±10%</td>
</tr>
<tr>
<td>D.C. RESISTANCE</td>
<td>@20°C</td>
<td>0.0135 ohms ±20%</td>
</tr>
<tr>
<td>INDUCTANCE</td>
<td>10kHz, 100mV, Ls</td>
<td>520.8μH ±10%</td>
</tr>
<tr>
<td>SATURATION CURRENT</td>
<td>20% rolloff from initial</td>
<td>540mA</td>
</tr>
<tr>
<td>LEAKAGE INDUCTANCE</td>
<td>tie(9+7), 100kHz, 100mV, Ls</td>
<td>42μH typ., 80μH max</td>
</tr>
<tr>
<td>DIELECTRIC</td>
<td>4000VAC, 1 second</td>
<td>4000VAC, 1 minute</td>
</tr>
<tr>
<td>DIELECTRIC</td>
<td>tie(7+5), 2000VAC, 1 second</td>
<td></td>
</tr>
<tr>
<td>TURNS RATIO</td>
<td>(3-5):(9-7)</td>
<td>17.33:1, ±3%</td>
</tr>
</tbody>
</table>
Magnetic Flux and Core Losses

\[ P_{Los} \propto f, \Delta B \]

- \( P_{Los} \) = Core losses
- \( f \) = frequency
- \( \Delta B \) = Gauss level

Lower \( \Delta B \)
Magnetic Flux and DC Magnet Effects

\[ B_{sat} = \frac{L_{prim} \times I_{peak}}{N_p \times A_e} \]

\[ B_{sat} - B_{DCmag} = \frac{L_{prim} \times I_{peak}}{N_p \times A_e} \]

\( B_{sat} \) = Core flux density
\( B_{DCmag} \) = External DC magnetic flux density
\( L_{prim} \) = Primary inductance
\( I_{peak} \) = Peak primary current
\( A_e \) = Core area
How to reduce DC Magnet Effects

- Increase physical or electrical distance between DC magnet and transformer core (shielding)
- Reduce the $B_{sat} - B_{DCmag}$ of the transformer
  - Increase the number of primary turns
  - Increase the core area
- Use other core materials
  - High $B_{sat}$ materials

\[
B_{sat} - B_{DCmag} = \frac{L_{\text{prim}} \times I_{\text{peak}}}{N_P \times A_e}
\]
Techniques to reduce DC magnet Effects on Transformers

- Typical B vs. H curve for different $\mu$

Examples for soft core materials
- Kool $\mu$
- Sendust
- High Flux
- Powdered-iron

Source: Magnetics technical note, Powder Core Loss Calculation
Ferrite cores vs Distributed Gap Cores

Summary

- DC magnetic effects can be reduced by
  
  1. Increasing the physical or magnetic path between external DC magent and transformer core (Shielding)

  2. Reducing the transformer gauss level (Increasing the primary turns or core area)

  3. Using cores with high Bsat (Soft saturation)
     - Distributed gap cores
     - Nanocrystalline core materials